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"Truth . . . and utility are the very same things"
Francis Bacon, *New Organon*, I, Aphorism 124

The emerging political economy of global science is a significant factor influencing economic, social and cultural development, building national systems of innovation, and the rise of new multinational corporate, private/public and community involvement.[1] It is only since the 1960s with the development of research evaluation and increasing sophistication of bibliometrics and webometrics that it has been possible to map this emerging economy of global science on a comparative national and continental basis.[2] The question of the political economy of world science and its geographic distribution cannot be easily separated from its measurement and evaluation or the pattern of journal ownership.

Increasingly, both firms and higher education institutions are emphasizing the economics and productivity of science as policy-makers and politicians seek to foster innovation and draw strong links between scientific performance and emerging economic structures (Crespi & Geuna, 2004, 2005). In these science policy discussions the accent often falls on measuring scientific productivity; "intellectual property" and the codification of knowledge; and research collaboration, partnership and cooperation in regional, national and international contexts. Investment in science, engineering and technology receives strong attention from governments as the basis of the "knowledge economy," and most governments now look to their international science policy strategy to reinforce national competitive advantage and encourage research collaboration in global science projects.

Indeed, it is the age of *global science*, but not primarily in the sense of "universal knowledge" (as characterized by the liberal meta-narrative of "free" science since its early development), in which scientific findings are open to peer review and public scrutiny and, in principle, are reproducible by others following the same procedures.[3] It is

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1 This paper draws on material from Peters, 2006.
2 The Science Citation Index provides bibliographic and citational information from 3,700 of the world's scientific and technical journals covering over one hundred disciplines. The expanded index available in an online version covers more than 5,800 journals. Comparable 'products' in the social sciences (SSCI) and humanities (A&HCI) cover, respectively, bibliographic information from 1,700 journals in fifty disciplines and 1,130 journals.
3 'Truths' established through these scientific norms have, thus, always been considered universal or so some positivist philosophers of science maintain — and there is *some* sense to this claim, although its content is notoriously difficult to unpack. The problem of truth of scientific knowledge in this

the age of global science but not necessarily in the sense of “international” collaboration typified by the free exchange of ideas, free inquiry and collaboration developed during the so-called “scientific revolution” and period of classical science when “scientists,”[4] particularly within Europe, travelled to meet one another and share ideas. This was the period when learned societies were established and the first journals flourished with the growth of publishing during the 17th and 18th centuries, helping both to generate the international exchange of theories, concepts, methods and discoveries, and aid the processes of research collaboration.

This (older) liberal meta-narrative of science has now been submerged by official narratives based on an economic logic linking science to national purpose, economic policy, and national science policy priorities. In the era of “post-normal” science (Funtowicz & Ravetz, 1992), globalized corporate science dominates the horizon and scientific “outputs” take the form of patents, unpublished consultancy, and “grey literature,” or are covered by legal arrangement and “lawyer-client confidentiality.” Quality assurance replaces “truth” as the new regulative ideal. As a result, there are concerns about the fate of traditional peer-reviewed scientific publishing. The rise of digitized publications has led to a counter-revolution in scholarly publishing where actual sales are recast into licenses and commercial publishers are taking advantage of the growth of open archives (Guédon, 2001). The Select Committee on Science and Technology in the United Kingdom Parliament (2003), for example, urged adoption of a new government strategy to address the problem of increasing journal prices imposed by commercial publishers, by recommending “all UK higher education institutions establish institutional repositories on which their published output can be stored and from which it can be read, free of charge, online.”[5]

Global science, as a term, describes the emerging *geography of scientific knowledge and collaboration* as an aspect of globalization and interconnectedness within a globalized world. This is a distinctly new phenomenon, although, judging by scholarly criteria, it still reflects strong Western control and bias, is heavily nationalistic, and is seen as a vital part of national culture and state economic policy. In modern Baconian statecraft, science

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respect is especially difficult to fathom, given the competing accounts of truth and their (different) role within the sciences (natural and social). The easy philosophical examples tend to abstract individual statements from their theory contexts; yet the ‘truth’ of theories in science is more complex as scholars like Popper, Lakatos and Feyerabend have demonstrated, suggesting that it serves as a regulative ideal. I do not want to deny ‘truth’ of scientific knowledge or its ‘universality’ yet I want to emphasize that questions of truth and validity should not obscure that the institutionalization of science has strongly reflected patterns of national, corporate and multinational interests.

4 I have put the word scientist in inverted commas because the term was not used until relatively recently, after the institutionalization of natural philosophy and the professionalization of science. Most ‘scientists’ in the period of the institutionalization of science were often wealthy gentleman amateurs, like the botanist Joseph Banks, for instance, who became president of the Royal Society nearly 120 years after its establishment. On biographies of Fellows of the RS see http://www.royalsoc.ac.uk/page.asp?id=1679 and for a broader account of ‘antebellum American science’ see, e.g. Clark Elliot’s review and bibliography at http://home.earthlink.net/~claelliott/index.html.

5 Lyotard (1984) raised similar questions a generation ago. See my *Education and the Postmodern Condition* (Peters, 1996) and, more recently, *Building Knowledge Cultures* (Peters & Besley, 2006).

belongs to a knowledge economy and is the source of innovation and growth in productivity. To a large extent, the developing infrastructure of global science is an outgrowth of earlier historical conditions. The incipient infrastructure provided by "colonial science" of the European expansionist era was arguably the *first* phase in the globalization of science. More recent developments include the industrial-military research complex established during the two world wars which extended through the nuclear escalation and space race of the Cold War period. On one reading, the term global science reflects an extension of the "old" liberal (as opposed to the market-driven neo-liberal) ideology of "universal free knowledge" based on exchange and peer review that developed with the emergence of the modern research university in the 19th century. Yet it is also clear that it smacks of "imperial science"—science in the service of the empire—which strongly motivated Francis Bacon's new philosophy and the views of the founders of the Royal Society in the 17th century during the early institutionalization of British science. At the same time, the emergence of "global science" also reflects new global exigencies, new global problems, and an enhanced global network of science communicative practice. Today, "big science" projects require massive state and intergovernmental funding support in an era of intense international competition for knowledge assets. These dynamics have forced governments and institutions to collaborate with one another. International science agencies also recognize the need for cooperation on pressing global issues that run across borders, such as global warming and other ecological problems, AIDS/HIV and other global diseases and virus outbreaks, natural species extinction, preservation of biomass features, and so forth.

The term "big science" actually dates back to the late 1950s when it was used to herald the transition from individual to team research and development. The term was employed to refer to large scale, instrument-expensive, government-funded projects in areas of basic science (such as high-energy physics), space research, and military science. The term also heralded shifts in science policy and funding after WWII.[6] Derek J. de Solla Price (1963) in *Little Science*, *Big Science* applied publications analysis to science communication practices, providing the first systematic approach to the structure of modern science, and helping establish bibliometrics and scientometrics as essential to evaluating the productivity of scientific research. In conceptualizing "big science," the Organization for Economic Co-operation and Development (OECD) Global Science Forum[7] puts it this way:

> Big Science is global. Research and development in medicine, technology, engineering, chemistry, biology and physics have long since overrun national

6 For an introduction to the literature on changes to sciences after WWII see, for instance, Alexei Kojevnikov course at http://www.aip.org/history/syllabi/postwar.htm.

7 The OECD Global Science Forum started as the 'Megascience Forum' in 1992, focusing on Big Science projects (ultra high-energy neutrinos electron accelerator facilities, nuclear physics and global biodiversity) and was expanded as the Global Science Forum in 1999 with the aim of addressing more basic issues (e.g. short-pulse lasers, neuro-informatics, outer space airwaves). See OECD Observer at http://www.oecdobserver.org/news/fullstory.php/aid/1019/Global_science.html. On OECD best practices for establishing scientific cooperation and managing large-scale projects see http://www.oecd.org/department/0,2688,en_2649_34319_1_1_1_1_1,00.html.

> borders, in part because no single government has the time, money or indeed skills that such work demands. Projects, from the International Space Station to building particle colliders and light sources, or semi-conductor research: all thrive on global co-operation. It was not always so. Governments, scientists and investors have often been wary of each other, with co-operation tending to take place on an ad hoc basis.

The OECD puts an emphasis on “Big Science” and adduces resources-based imperatives as driving global cooperation. Yet global science *per se* does not reduce simply to “big science,” even though it may account for genuine attempts to build international cooperation and adopt a strategic approach to collaborative partnerships at the extra-national level. Bilateral and regional science and technology relations, of course, go back a long way, relatively speaking. In the early 1950s, the European Laboratory for Particle Physics (CERN) in Geneva was the result of cooperation among European governments which now has member scientists from both European and non- European countries. The European Science Foundation (ESF)[8] was created in 1974 and established a scientific network in the early 1980s for the coordination of European science based in various subject group areas such as Physical and Engineering Sciences, and Life, Environmental and Earth Sciences. In the early 1990s, the ESF also set up research linkages with Asia and Asia-Pacific Economic Cooperation (APEC) established protocols for scientific cooperation among its members.[9] Scientists, sponsored by world organizations like UNESCO and Food and Agriculture Organization (FAO), set up global research programs, based on obvious cross-border exigencies. Earth scientists, in particular, have been instrumental in establishing international research programs dealing with the dynamics of the earth system such as the Global Climatic Observation System,[10] the Global Ocean Observation System[11] and the Global Terrestrial Observation System.[12]

Yet these recent examples of extra-national scientific collaboration do not take account of the many smaller institutional exchanges and partnerships, such as university consortia for across-the-board cooperation, or firm/university partnerships. Nor does it take account of the increasingly multinational corporate nature of international research undertaken by world conglomerates like Monsanto and other biotech companies or large pharmaceutical companies. Some of these partnership arrangements and examples of multinational science probably fit better into theories of globalization than traditional university-based collaborations.

The emergence of global science, thus, conforms to both the global business model based on the market and the science model based on free exchange of give and take. The development economist, Amartya Sen (2002), for instance, makes the following

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8 See the ESF website at http://www.esf.org.
9 See the ASEM Science and Technology Ministers’ Meeting, on which some of this article is based, at http://europa.eu.int/comm/external_relations/asem/min_other_meeting/sc_tech_comque.htm and also *Connecting Asia Pacific and Europe (CAPE)* 1998 at http://www.dante.net/cape/-cape.html.
10 See http://www.epa.gov/geoss/.
11 See http://ioc.unesco.org/goos/.
12 See http://ioc.unesco.org/goos/.

observation, which is essential to understanding the different kinds of associations needed for development: "Contrast the sharing that underpins science with the transactional nature of market relations. The market mechanism is not only an important social institution it is also an organizational ideology. Its success—perceived as well as real—can help stifle independent thinking about interactive relations of other kinds, including that of give and take. The gaps it leaves are worth filling since sharing is not only crucial to science, it is also central to development.

Not only does Sen contrast science with the market but he argues for a position that views science as a global tradition, avoiding the "anti-Western" globalization sentiments as well as Western chauvinism and a proprietary approach to "Western science." He explains, for example, that Western science draws upon world heritage (e.g. the mathematics of Al-Khwarizmi). Yet Sen does not contemplate the rise of global science or the complex ways in which it proceeds on mixed models that integrate traditional "science sharing" (as he calls it) and market relations. Such models are especially evident in the emerging international regime of "intellectual property" rights through the World Trade Organization (WTO). In a sense, Sen avoids the difficult question of scientific hegemony based on private and cultural ownership of scientific discoveries, inventions, and insights (see e.g. Tudge, 2004).

On a global scale, it is now possible to get some idea of *science distributions* in terms of academic papers. A bibliometric analysis of 20 years of world scientific production (1981-2000), as reflected by the publications indexed in the Science Citation Index (SCI) reveals the following shifts:

> In 2000 the SCI included a total of 584,982 papers, representing a 57.5% increase from 1981, when 371,346 papers were published worldwide. Authors with addresses in developed countries wrote 87.9% of the papers in 2000, a decrease from 93.6% in 1981. Developing countries, on the other hand, saw a steady increase in their share of scientific production: from 7.5% of world papers in 1981 to 17.1% in 2000.… Since 1981 the world map of publications changed significantly. North America lost the lead it had in 1996, and in 2000 produced 36.8% of the world total, a decrease from 41.4% in 1981. The opposite trend can be found in the European Union, which in 2000 published 40.2% of the world total, up from 32.8% in 1981. Japan went up from 6.9% to 10.7% in 2000. Collectively this "triad" has therefore maintained its dominance, accounting for 81% of the world total of scientific publications in 2000, up from 72% in 1981.

The SCI includes publications in biology, biomedicine, chemistry, clinical medicine, earth and space, engineering and technology, mathematics, and physics. Sub-Saharan African publications remained stable at around 1% of the world total, and the share of publications from the Arab States increased from 0.6% in 1981 to 0.9% in 2000, while the Central Eastern European share remained stable around 3% of the world total. However, both the Newly-Industrialized Countries (NIC) in Asia (a group that includes China) and Latin America and the Caribbean (LAC) increased their share significantly, respectively, from 0.6% of the world total in 1981 to 4.2% in 2000 (with China accounting for 85% of the publications an increase from 63% in 1981), and 1.3% to 3.2% in LAC countries.

This bibliometric analysis indicates that the developed world's share of publications has declined while developing regions (Asia and Latin America) have expanded and Africa has stagnated. There is also clear evidence there has been considerable growth in international collaboration. These bibliometric measures do not include book citations, important for the humanities and social sciences, and they tend to favor English as the global medium of communication. Nevertheless, used with caution, as the UNESCO publication suggests, they do reveal trends regarding aspects of scientific production at global level.

A study of the output and outcomes from research investment over the past decade by Britain's Chief Scientist David A. King (2004) measures the quality of research on national scales and sets it in an international context. His analysis reveals the unevenness of world distribution of science and the ascendancy of a group of 31 countries[13] that account for "more than 98% of the world's highly cited papers, defined by Thomson ISI as the most cited 1% by field and year of publication: the world's remaining 162 countries contributed less than 2% in total" (p. 311). King notes the overwhelming dominance of the United States, whose share has declined recently, United Kingdom and Germany, and the fact that "nations with the most citations are pulling away from the rest of the world" (p. 311):

> The countries occupying the top eight places in the science citation rank order… produced about 84.5% of the top 1% most cited publications between 1993 and 2001. The next nine countries produced 13%, and the final group share 2.5%. There is a stark disparity between the first and second divisions in the scientific impact of nations. Moreover, although my analysis includes only 31 of the world's 193 countries, these produce 97.5% of the world's most cited papers (p. 314).

According to King, "the political implications of this last comparison are difficult to exaggerate. South Africa, at 29th place…is the only African country on the list. The Islamic countries are only represented by Iran at 30th, despite the high GDP of many of them and the prominence of some individuals, such as Nobel prizewinners Abdus Salam (physics, 1979) and Ahmed Zewail (chemistry,1999)" (p. 314).

Despite King's conclusions, there are clear signs that the architecture of global science is shifting, especially with the huge investment in research and the consequent growth of scientific publications in Asia. Adams and Wilsdon (2006) report that China's spending on research has increased by more than 20% per year, reaching 1.3% of GDP in 2005, making it third in the global league in research expenditure after U.S. and Japan. Science

13 The countries are: Australia, Austria, Belgium, Brazil, *Canada*, China, Denmark, Finland, *France*, *Germany*, Greece, India, Iran, Ireland, Israel, *Italy*, *Japan*, Luxembourg, the Netherlands, Poland, Portugal, *Russia*, Singapore, Spain, South Africa, South Korea, Sweden, Switzerland, Taiwan, the *United Kingdom* and the *United States* (with G8 countries in italics).

budgets in India have increased by the same annual percentage, and every year the country produces some 2.5 million IT, engineering and life sciences graduates, 650,000, postgraduates and 6,000 PhDs.

The U.S. National Science Board's (2008) publication *Research and Development: Essential Foundation for U.S. Competiveness in a Global Economy* charts the decline since 2005 of federal and industry support for basic research which accounted for 18% ($62B) of the $340B U.S. research budget in current dollars in 2006:

> Federal obligations for academic research (both basic and applied) and especially the current support for National Institutes of Health (NIH) (whose budget had previously doubled between the years 1998 to 2003) declined in real terms between 2004 and 2005 and are expected to decline further in 2006 and 2007. This is the first multiyear decline in Federal obligations for academic research since 1982.

The report also clearly shows the declining competiveness of U.S. science and technology: patents dropped from 55% in 1996 to 53% in 2005; and, "basic research articles published in peer-reviewed journals by authors from U.S. private industry peaked in 1995 and declined by 30% between 1995 and 2005…. The drop in physics publications was particularly dramatic: decreasing from nearly 1,000 publications in 1988 to 300 in 2005." The loss in U.S. share in science and technology "reflects the rapid rise in share by the East Asia-4 (comprising China, South Korea, Singapore, and Taiwan)." The U.S. needs a comprehensive strategy based on an understanding of the globalization of science, the promotion of innovation through international collaboration and the global value chain if it is to remain competitive in the coming decades.[14]

It is clear that the age of global science has arrived. This is manifested not only in the growth of multinational corporate science but also mandated in administrative and organizational structures that are both regional and rhetorically "global." For instance, Euroscience was founded in 1997 to "provide an open forum for debate on science and technology; strengthen the links between science and society; contribute to the creation of an integrated space for science and technology in Europe; influence science and technology policies."[15] Framework 6 for funding of science in Europe is approximately 16.27 billion Euros, an increase of 17% over the previous Framework 5. This funding program constitutes an estimated 5% of the research budget of EU countries overall and yet is seen to play a crucial role in structuring European research by defining the aims of European science and funding collaborative activity among scientists in Europe. Of the seven program areas, biotechnology and information technology account for well over 40% of total funding, with the rest shared by nuclear energy, nanotechnology,

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14 The author participated in a two day follow-up workshop 'Developing Evaluations Approaches to International Collaborative Science and Engineering Activities' on July 28 and 29, 2008 at the National Science Foundation. The report can be accessed at the Sigma Xi website at the following URL: http://www.sigmaxi.org/programs/global/index.shtml.

15 See http://www.euroscience.org/about.htm. See also the European Science Foundation at http://www.esf.org/.

aeronautics, food safety, and sustainable development and global change (see also Simons & Featherstone, 2000).

At the same time, U.S. science policy and science advocacy now cluster around the buzz words “bioinformatics,” “Bose condensates,” “genomics,” “nanotechnology,” “supersymmetries,” and “wavelets,” and there have been increases in the science budget, reorganization of science councils under Clinton, and increasing politicization of domestic science issues under Bush (Bromley & Lubell, 2003).16 Meanwhile, administrators like Bruce M. Alberts (1998, p. 26), president of the National Academy of Sciences (NAS), are calling for a “global science”:

> A major aim of the National Academy of Sciences (NAS) is to strengthen the ties between scientists and their institutions around the world. Our goal is to create a scientific network that becomes a central element in the interactions between nations, increasing the level of rationality in international discourse while enhancing the influence of scientists everywhere in the decision making processes of their own governments.

Clearly, communications technologies are crucial to the strategy for enhanced collaboration. Alberts indicates that “electronic communication networks make possible a new kind of worm science” and emphasizes “that we are only at the very beginning of the communications revolution,” which promises greater commercialization with attendant benefits for the developing world (p. 27). He also mentions that the National Research Council (the operating arm of NAS and the National Academy of Engineering) will attempt to prepare an international science road map to help the State Department.

In her article on the National Science Board (NSB) report, “Toward a More Effective

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16 The Bush administration did not appoint an influential, cabinet-level science adviser. It was, in fact, the slowest administration ever to fill the top 500 positions in government and left many science-related agencies leaderless. The Bush administration also became notorious for politicizing the membership of scientific advisory committees (see Mooney, 2005). By contrast, Obama laid out his science policy in considerable detail well before the election, naming his science team as follows: Harold Varmus, a Nobel laureate and former head of the National Institutes of Health; Gilbert Ommen, a former president of the American Association for the Advancement of Science; Peter Agre, a Nobel laureate and ardent critic of the Bush administration; NASA researcher Donald Lamb; and Stanford University plant biologist Sharon Long. Obama promised to increase funding for basic research in physical and life sciences, mathematics and engineering at a rate that would double basic research budgets over the next decade. He also promised to lift the Bush administration’s ban on federal funding of research on embryonic stem cell lines and ‘restore the basic principle that government decisions should be based on the best-available, scientifically valid evidence and not on the ideological predispositions of agency officials or political appointees’. For further detail and comparison see Science Debate at http://www.sciencedebate2008.com/www/index.php.

Role for the US Government in International Science and Engineering," Paula Park (2002, p. 8) notes that it "encourages agencies to evaluate whether new immigration and intellectual property policies and regulations will affect international science cooperation." Quoting Eamon Kelly, chairman of the NSB, Parks emphasizes that "the future of the developing countries rests on their ability to adapt to a culture of science and technology in the 21st century." Hal Cohen (2003) indicates that scientists themselves are establishing global organizations. The International Council of Scientific Unions created in 1931 was recently renamed the International Council for Science. It has established several programs, including one in biology (1964–1974). Current programs include the International Geosphere-Biosphere Program and the World Climate Research Program (following the Kyoto Protocol). Going back to the late 1980s, the OECD tried to establish a set of guidelines covering all aspects of international relations in science (Dickson, 1987, p. 743) which included a focus on "the extent to which each country should contribute to the world's basic research effort and the conditions under which foreign research workers are permitted to attend scientific meetings." Much of the initiative under the Reagan administration emphasized policing and protection of intellectual property rights within the protocols of General Agreement on Trade in Service (GATS) and WTO.

Within these emerging structures of global science, collaboration takes many different forms. Increasingly, under neo-liberalism it presupposes a competitive relationship which is the main form of collaboration between Europe and the U.S. This normally revolves around the shared investment of personnel and resources and is directed at cutting edge science and technology. Public-private partnerships increasingly take on an international dimension especially in relation to aeronautics and space research. Over and above these international forms are collaborative relationships not premised on competitive criteria but, rather, on forms of "cooperation" or "assistance" that fall within traditional development aid categories.

There is perhaps, a third category, which has been a feature of U.S. science policy since the 1960s. It is the relation between expertise and governance. This form draws networks back to their funding bases and organizational homes in universities and laboratories and raises interesting questions concerning a shift in the university from knowledge to expertise. In discussing developments of the emerging world knowledge system and, in particular, the structures of international research collaboration it is necessary to locate the merging systems within the historical context, a context that reveals the politics and competitive nature of collaboration and the leading position of the U .S.-Europe constellation. In the age of knowledge capitalism where knowledge increasingly is seen to be the basis of national competitive advantage, the emphasis has fallen on policing and reinforcing intellectual property rights regimes and forms of knowledge hoarding, especially with the growth of multinational science and the privatization of science funding regimes. While there are encouraging signs that India and China (especially relating to foodstuffs, information science and microchip production, and space research) are developing a more competitive science base, their science sectors pale into insignificance when compared to the West. Recently, Western governments, especially the U.S., have expressed some concern over the increasing outsourcing of R&D

functions, especially the training of technicians and scientists who work for much less money on contract without the normal employment benefits of Western scientists. There are some forms of global science and international collaboration that conform to the more traditional liberal justifications of science and emphasize its status as a global public good (Stiglitz, 1999).

Be that as it may, there is a diversity of forms of global science that have emerged from existing infrastructures and histories that strongly reflect politics—not merely the arms industry and the industrial-military research complex, but also colonial pasts and new "neo-imperial" forms based on trade agreements, or those that work against this hegemony to link science into global social democracy efforts in the service of global civil society based on the needs of the world's population. Universities encourage both competitive and non-competitive forms of international collaboration. Increasingly, however, with the decline of state funding of higher education in the U.S. and the development of nearly 200 science research parks nationwide, the latter is giving way to the former as institutions struggle to diversify their funding bases with venture capital funding spin-off companies, patenting university discoveries, and attracting leading multinationals to campus. A major question is whether the funds accrued from competitive forms of collaboration will be used to help support and subsidize non-competitive forms of collaboration. In other words, can the university subscribe to twin legitimating discourses that embrace social justice goals as well as accommodate for-profit motives. It may well be that technology dependent "sharable goods" as one form of social production and exchange (Benkler, 2004), alongside the state and the market, will emerge as a third mode of organizing science production, bringing in its wake changes in the material conditions of production of the networked information economy that encourage non-propriety forms of academic production and facilitate international research collaboration.

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